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Switchyard Enclosure Bolted Connection Calculations

Becky Patton

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TO: Switchyard Enclosure Design File

FROM: Becky Patton

SUBJECT: Switchyard Enclosure Bolted Connection Calculations

The maximum deflection and the maximum stress were calculated for the bolted connection of the flanges. The stress is a result from both the air pressure inside the beam enclosures as well as the force from the compressed p-gasket. The results of the calculations are shown below in Table 1 for each of the four beam enclosure types. The Safety Factor was calculated using a yield strength of 41 ksi[1].

Table 1 Maximum Deflection and Stress for the Flange.

	Quad	Quad Intermediate	Bundle	Double Quad
Maximum Deflection (psi)	0.0016	0.0012	0.0014	0.0016
Maximum Stress (psi)	2902	2340	2598	2782
Safety Factor	14.1	17.5	15.8	14.7

Calculations were also performed on the M8 bolts that are used to connect the flanges. Both the internal air pressure and the force of the compressed p-gasket induce the normal stress. The shear stress is from the weight of the unsupported beam enclosure (see Figure 1 on page 3). The calculated maximum stresses and the resulting safety factors are given in Table 2. The safety factors were calculated using the maximum shear stress hypothesis and a yield strength of 30 ksi.

Table 2 Maximum Stresses and the resulting Safety Factors for the Bolts.

	Quad	Quad Intermediate	Bundle	Double Quad
Maximum Normal Stress (psi)	783.8	744.1	766.9	794.8
Maximum Shear Stress (psi)	400.9	389.1	392.9	408.0
Safety Factor	37.4	38.5	38.2	36.2

The following pages are the hand calculations that were performed to yield the above results.

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[1] This value is the yield strength for the flanges as reported in the material certifications provided by the fabricator.

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Flange Calculations
The definitions of the symbols and the equations used to perform the flange calculations can be found in the NIF document NIF-0045930[2].

Constants:
w_f = 2.0 in
t_f = 0.1875 in
F = 8.6 lb/in (This is the largest force found from the tests performed on the gaskets. See NIF-0053474[3])
p_i = 0.145 psi
σ = 0.1875 in
E_f = 29E6 psi

Table 3 Variables

	Quad	Quad Intermediate	Bundle	Double Quad
B_s (in)	6.85	6.35	6.69	6.92
a (in)	46.89	49.84	49.84	94.45
b (in)	49.84	38.49	78.39	49.84
c (in)	45.28	48.23	48.23	92.82
d (in)	48.23	37.23	76.77	48.23

Equations:

$$s = \frac{\pi\delta}{2} \qquad \text{(eq. 1)}$$

$$y_{\max} = \frac{B_s^4}{32E_f w_f t_f^3}\left(F + \frac{[(a-s)(b-s)-cd]p_i}{a+b+c+d-2s}\right) \qquad \text{(eq. 2)}$$

$$\sigma_{\max} = \frac{B_s^2}{2w_f t_f^2}\left(F + \frac{[(a-s)(b-s)-cd]p_i}{a+b+c+d-2s}\right) \qquad \text{(eq. 3)}$$

Substituting the constants and the variables into equations 1 through 3 yields the maximum deflection and stress values given on the first page in Table 1. The Safety factors were found by dividing the yield stress (41 ksi) by the maximum stress.

[2] NIF-0045930, Summary of p-gasket / bolted connection seal flange equations, March 24, 2000
[3] NIF-0053474, Switchyard p-gasket 1st article inspection-AAA99-110341-OD, August 28, 2000.

Bolt Calculations

On each bolt there is the normal stress from both the pressure inside the enclosure and the force of the compressed p-gasket in addition to the shear stress caused by the unsupported enclosure (see Figure 1).

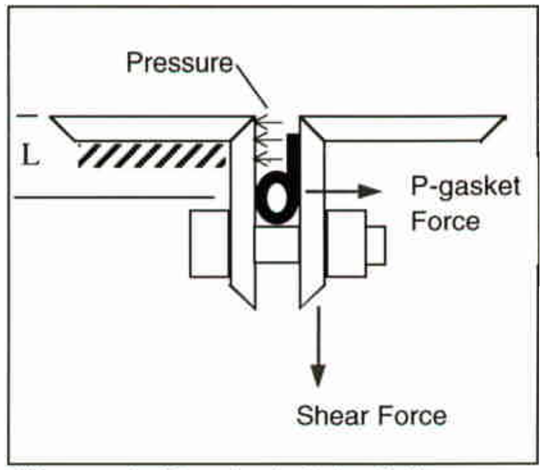

Figure 1 Rough sketch of the forces acting on the bolt.

Finding the normal stress:

A := Pressure Area
B_s := Bolt Spacing
L := (see Figure 1)
P := Internal pressure
F := Force per Unit Length of the gasket
F_p := Force of the internal pressure of the enclosure
F_g := Force of the p-gasket
F_R := Total force acting normal to the bolt
σ := Normal stress
A_b := Cross-sectional area of the bolt

The pressure force can be found by multiplying the magnitude of the pressure by the area it is acting on for each bolt. This area is said to be the space between bolts times the distance from the center of the p-gasket to the angled part of the flange.

$$A = B_s L \qquad \text{(eq. 4)}$$

Where L= 0.758 in

$$F_p = AP \qquad \text{(eq. 5)}$$

Where P=0.145 psi

Substituting equation 4 and the values for L and P into equation 5 gives:

$$F_p = 0.11 B_s \qquad \text{(eq. 6)}$$

The gasket force can be found by multiplying the force per unit length of the gasket by the distance between bolts.

$$F_g = B_s F \qquad \text{(eq. 7)}$$

Where F = 8.6 lb/in

The total force is the addition of the pressure force and the gasket force. Substituting F into equation 7 and adding the two forces gives the following:

$$F_R = F_g + F_p = 8.6 B_s + 0.11 B_s = 8.71 B_s \qquad \text{(eq. 8)}$$

To find the normal stress the total force is divided by the cross-sectional area of the bolt.

$$\sigma = \frac{F_R}{A_b} \qquad \text{(eq. 9)}$$

Where $A_b = 0.078\ \text{in}^2$

Substituting equation 8 and the value for A_b into equation 9 yields the following

$$\sigma = 111.8 B_s \qquad \text{(eq. 10)}$$

Substituting the B_s value of each enclosure type into equation 10 gives the normal stresses shown in Table 4.

Table 4 Bolt Spacing and the Normal Stresses

	Quad	Quad Intermediate	Bundle	Double Quad
B_s (in)	6.85	6.35	6.69	6.92
Normal Stress (psi)	765.9	710.0	748.0	773.7

Finding the Shear Stress:

τ := Shear stress

A_b := Cross-sectional area of the bolt

Dividing the weight of a 10 foot section of each enclosure type by the number of connecting bolts yields the shear force per bolt, as shown below in Table 5.

Table 5 Values used to find the force per bolt

	Quad	Quad Intermediate	Bundle	Double Quad
Weight of 10 ft Section (lb)	554.3	521.3	750.6	887.7
Number of Bolts	60	42	80	88
Force on Each Bolt (lb)	9.24	12.41	9.38	10.09

Dividing the force on each bolt by the cross-sectional area of the bolt (A_b) gives the Shear Stresses (τ) given in Table 6.

Table 6 Shear Stress

	Quad	Quad Intermediate	Bundle	Double Quad
Shear Stress (psi)	118.6	159.3	120.4	129.5

Finding the Maximum Normal Stress and the Maximum Shear Stress:

σ_m:= Maximum Normal Stress
τ_m := Maximum Shear Stress

$$\sigma_m = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} \qquad \text{(eq. 11)}$$

$$\tau_m = \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} \qquad \text{(eq. 12)}$$

Substituting the values found earlier for the normal stress and the shear stress into equations 11 and 12 yields the results shown in Table 7. (These results are also given on page 1 in Table 2)

Table 7 Maximum Stresses

	Quad	Quad Intermediate	Bundle	Double Quad
Maximum Normal Stress (psi)	783.8	744.1	766.9	794.8
Maximum Shear Stress (psi)	400.9	389.1	392.9	408.0

Finding the Safety Factor Using the Maximum Shear Stress Theory:

S_y := Yield strength of the bolt

$$SafetyFactor = \frac{S_y}{2\tau_m} \qquad \text{(eq. 13)}$$

Where S_y =30,000 psi

Substituting the values for S_y and τ_m into equation 13 yields the safety factors given below. (These results are also given on page 1 in Table 2)

Table 8 Safety Factors

	Quad	Quad Intermediate	Bundle	Double Quad
Safety Factor	37.4	38.5	38.2	36.8